מכון ויצמן למדע
WEIZMANN INSTITUTE OF SCIENCE

Experience @ Weizmann

Shikma Bressler, Weizmann Institute of Science

The Resistive Plate WELL (RPWELL)

- Single sided THick Gaseous Electron Multiplier (THGEM (== LEM))
- Coupled to segmented readout through material of high bulk resistivity $(10^8 - 10^{10}\ \Omega cm)$
  - Combining MPGD and RPC concepts
- *Discharge free operation at high gain depending on the primary ionization* $(10^4 - 10^7)$
- Moderate rate capabilities

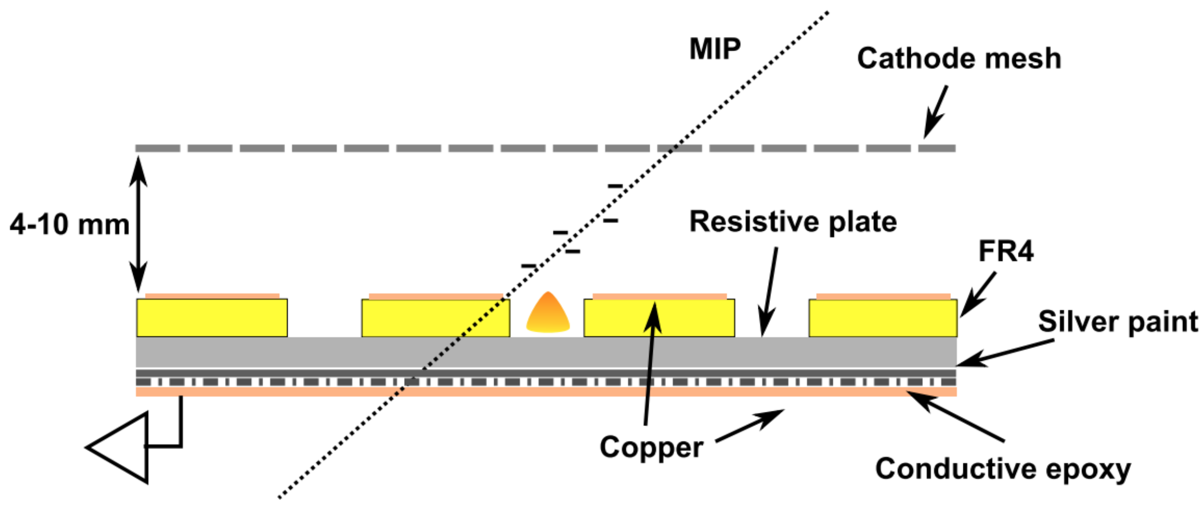


Figure 1. The Resistive-Plate WELL (RPWELL) configuration with a resistive anode and a readout electrode. The WELL, a single-faced THGEM, is coupled to a copper anode via a resistive plate. Charges are collected from the copper anode. In some experiments the WELL was directly coupled to the metal anode.

Studied and tested extensively by our group - main fronts

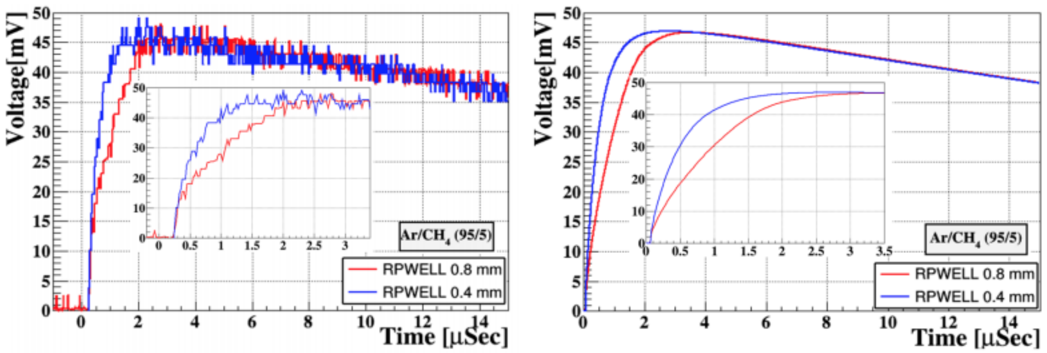
- Characterization
- Attempt to understand the physics processes governing its response
- Scaling up - transition from small- to large-area detectors
- Readout element in potential applications @ RT (DHCAL)

2013 JINST 8 P11004
2016 JINST 11 P01005
2016 JINST 11 P09013
NIM A 845 (2017) 262 -265
2017 JINST 12 P10017
2017 JINST 12 P09036
NIM A 958 (2020)

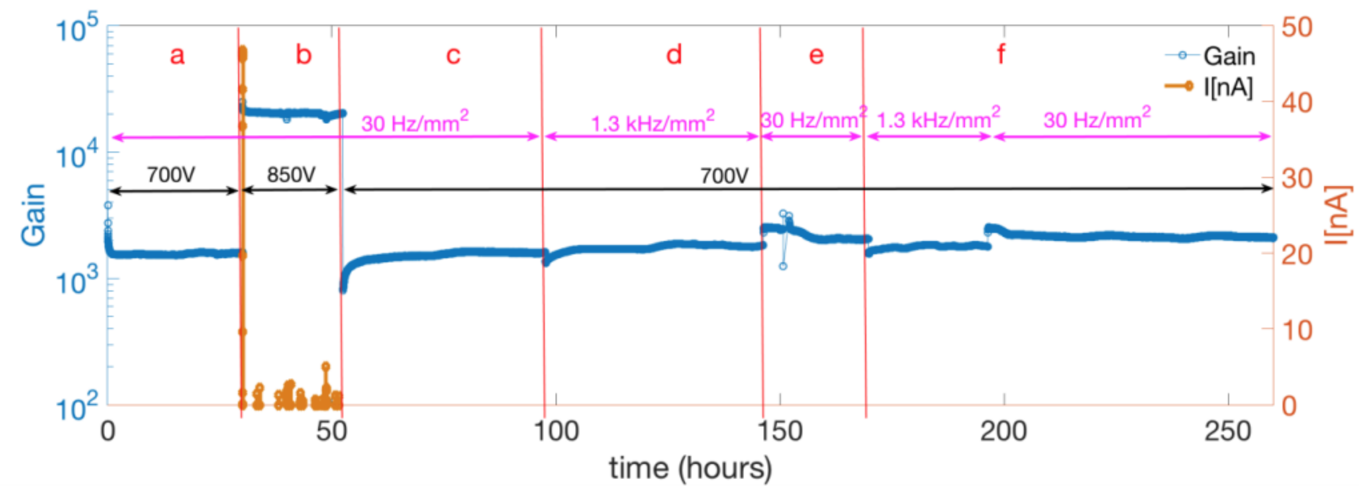
The RPWELL - Characterization & Physics

Looked at many properties in the context of different questions

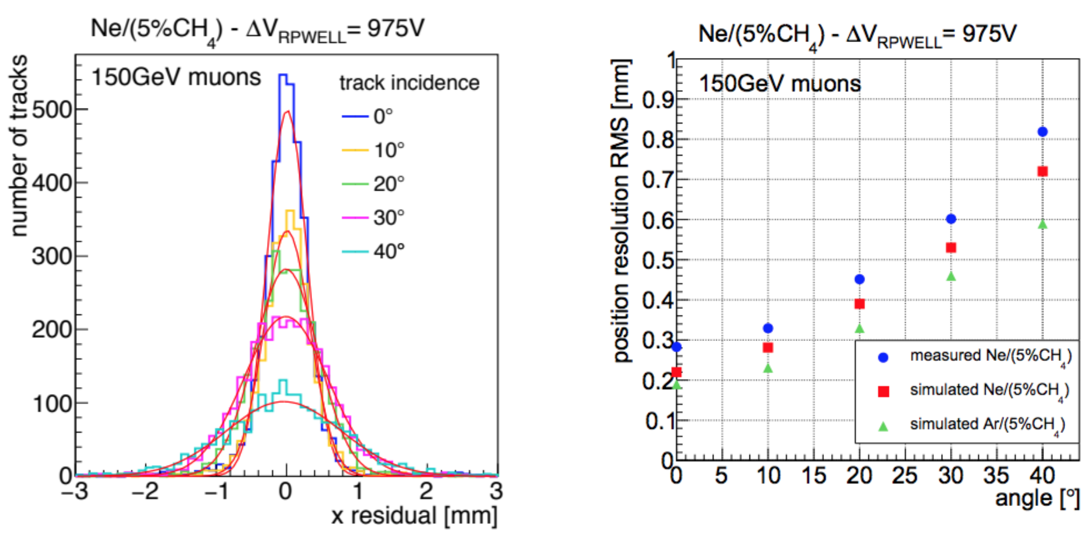
Signal formation 1810.12597
L. Moleri, P. Bhattacharya, SB



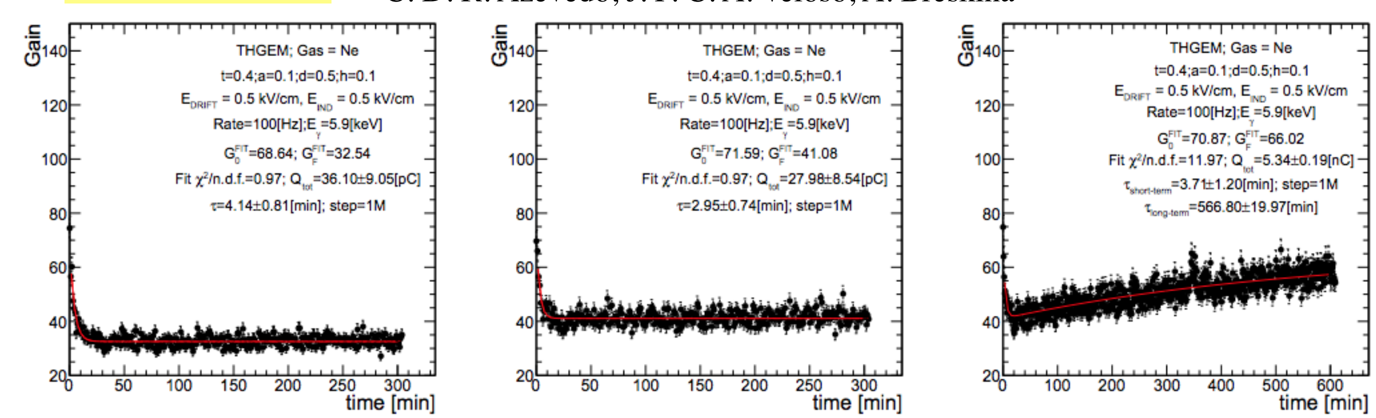
Stabilization 1707.04356
D. Shaked-Renous, A. Roy, A. Breskin, SB



Spatial resolution 1707.00125
L. Moleri, P. Bhattacharya, A.E.C. Coimbra, A. Breskin, SB



Stabilization 1801.00533
M. Pitt, P. M. M. Correia, SB, A. E. C. Coimbra, D. Shaked Renous
C. D. R. Azevedo, J. F. C. A. Veloso, A. Breskina

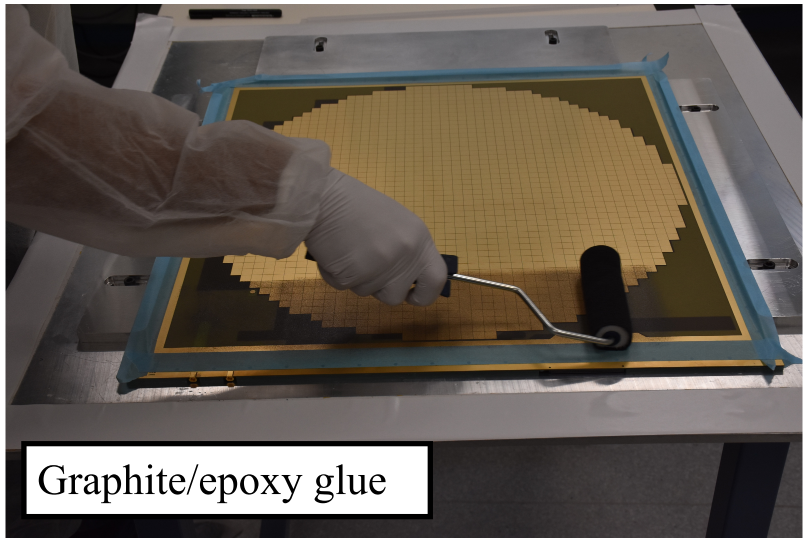


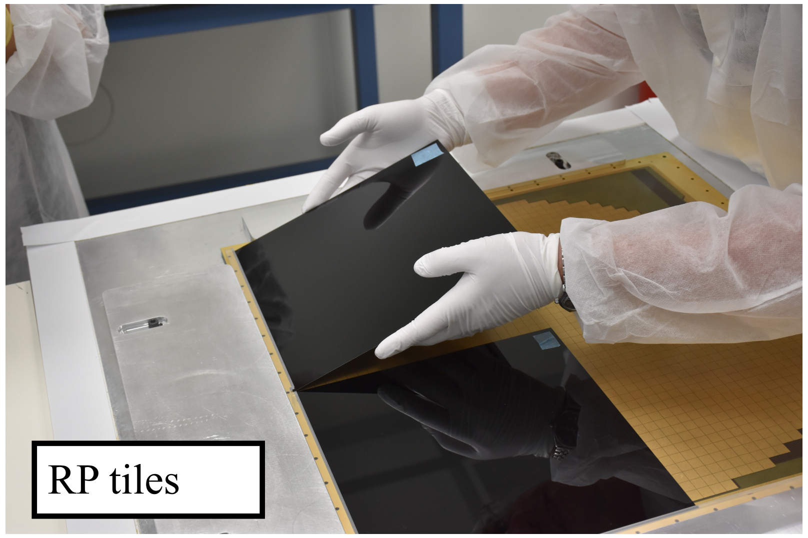
Still not all is clear

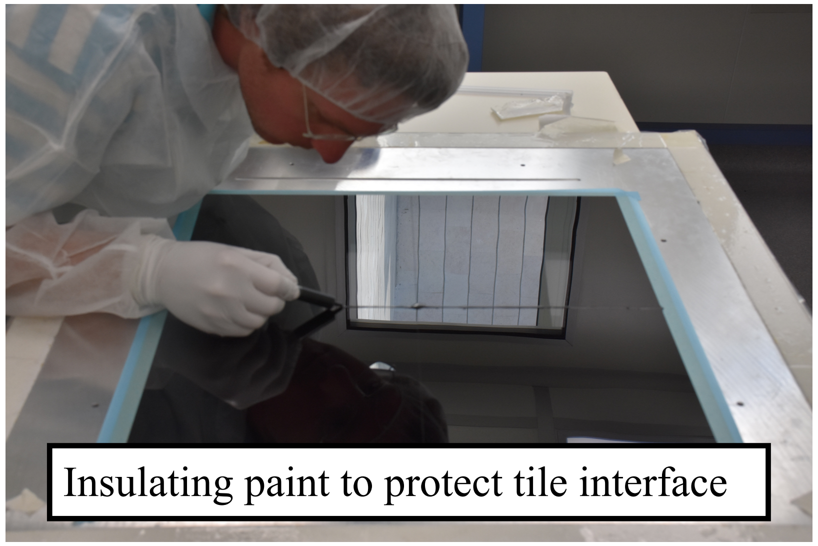
- Most important - modeling of the role of the resistive layer

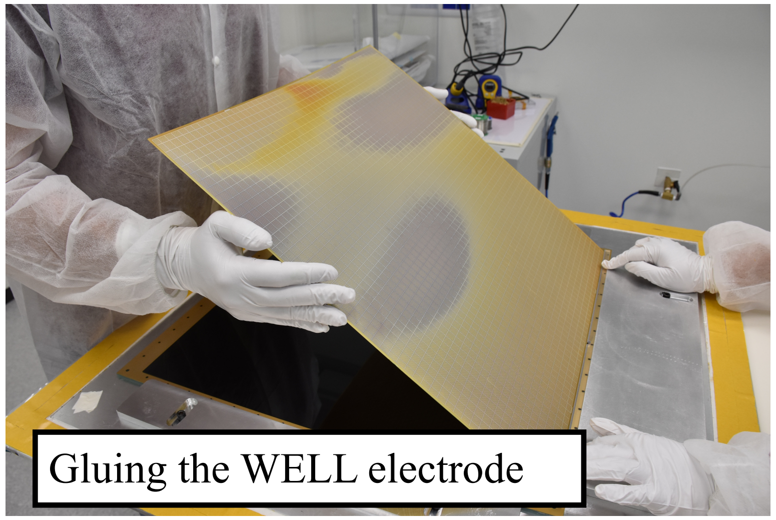
The RPWELL - Scaling up

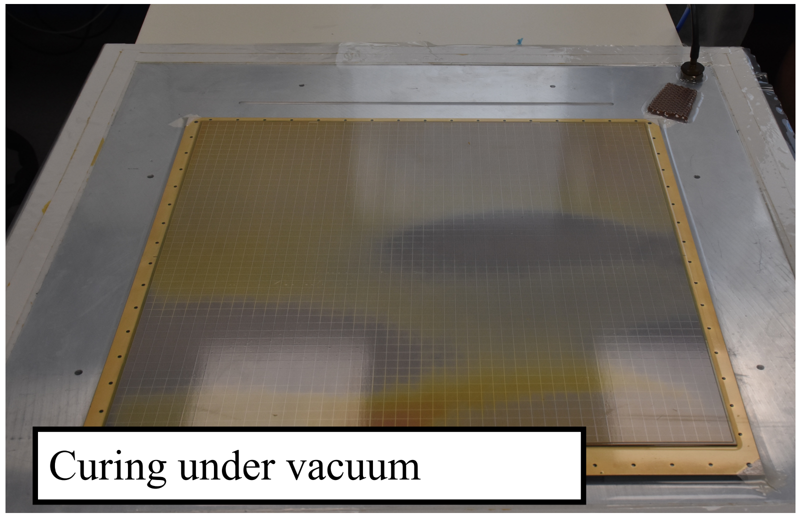
Assembly


Graphite/epoxy glue

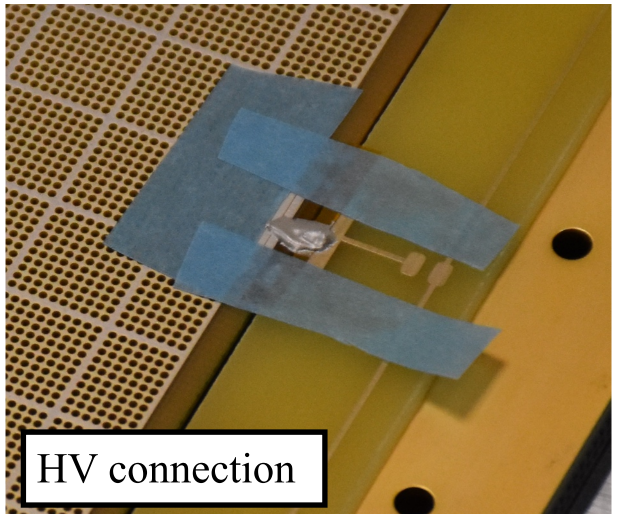

RP tiles

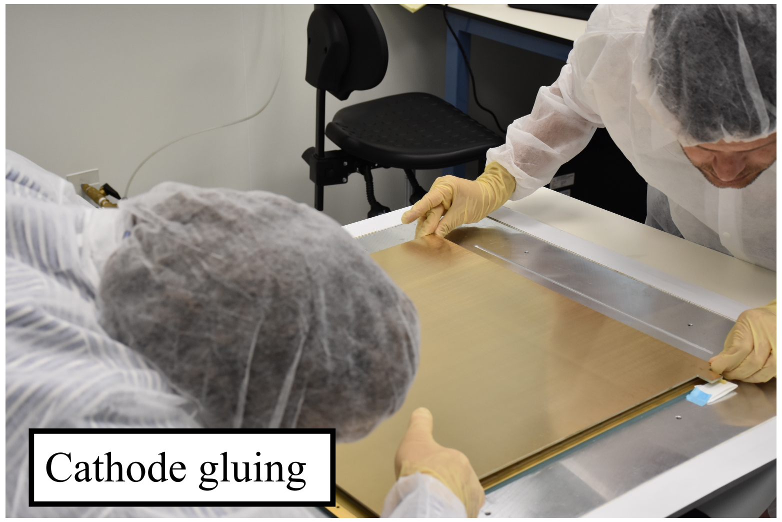

Insulating paint to protect tile interface

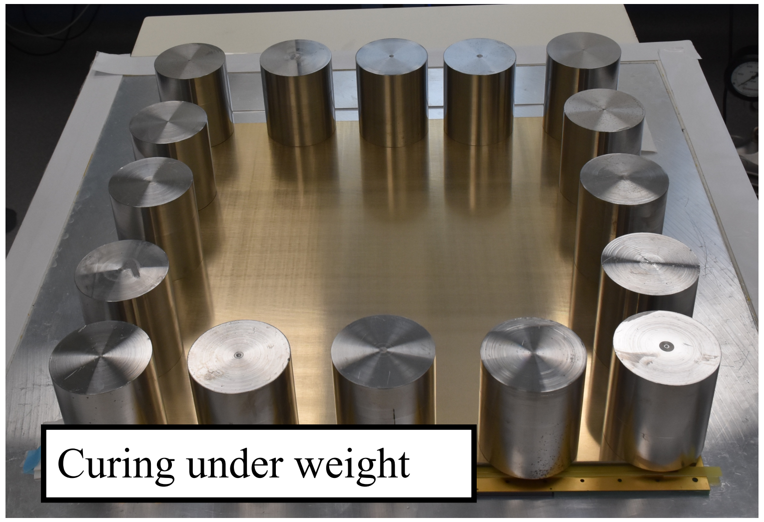

Gluing the WELL electrode


Curing under vacuum

Publication in preparation
A. Coimbra, L. Moleri, P. Bhattacharya, D. Shaked-Renous, SB


HV connection


Cathode gluing

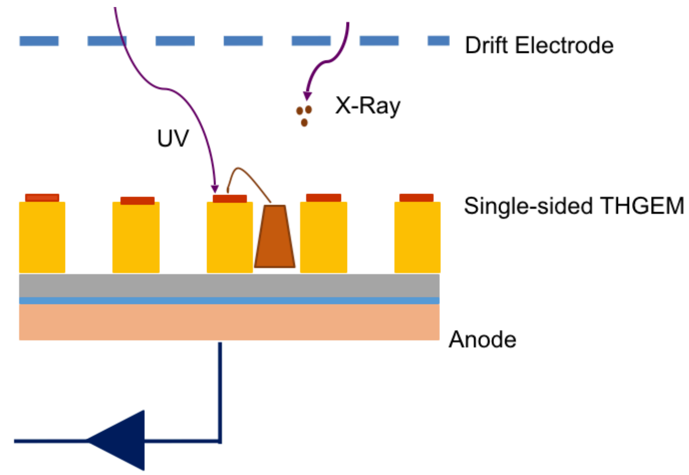

Curing under weight

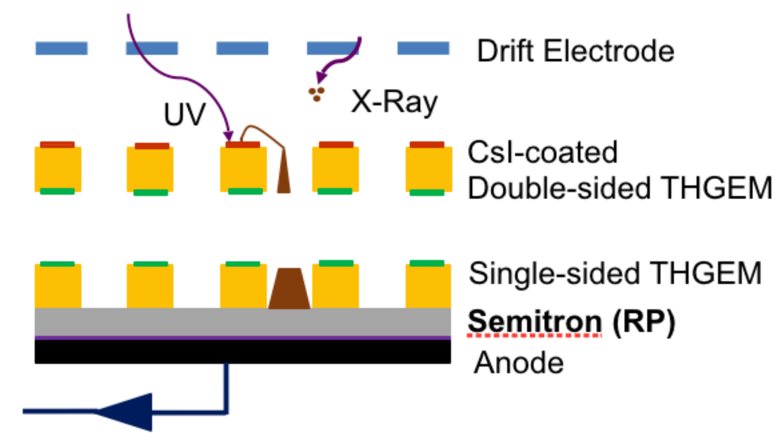
RPWELL - a single UV photon detector @ RT

Single- and double-stage configurations

- Source: Hg Lamp
- Ne & Ar-based gas mixtures

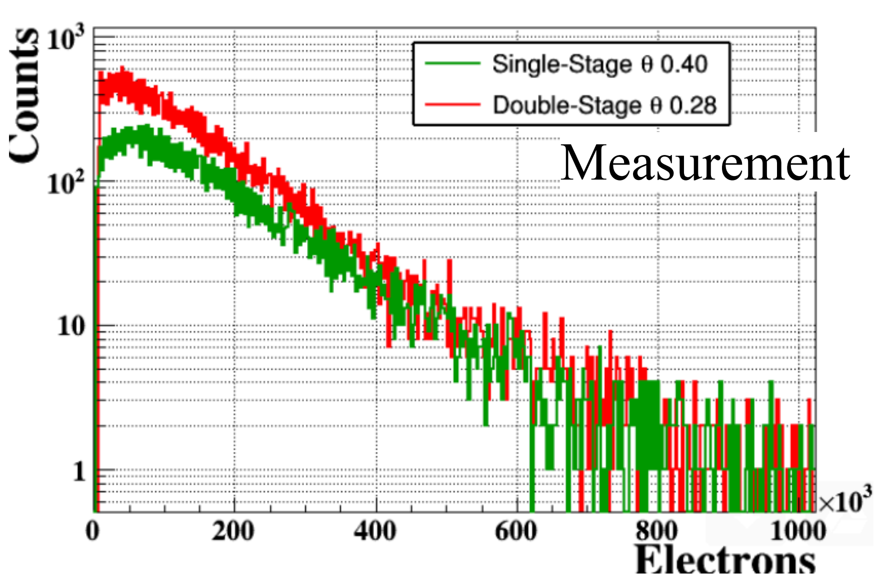
- Measured Polya distribution
  - paves the way toward high PDE
- Stable operation at high gains

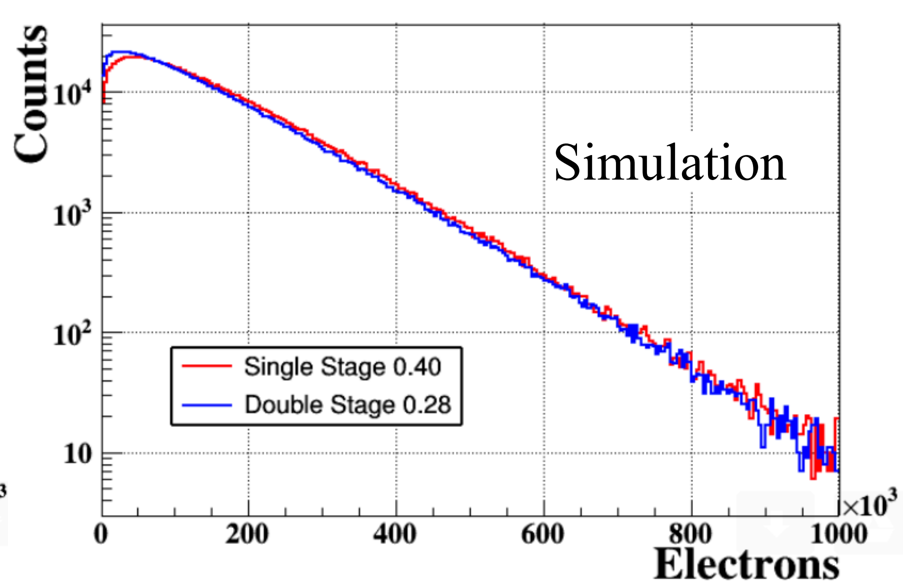


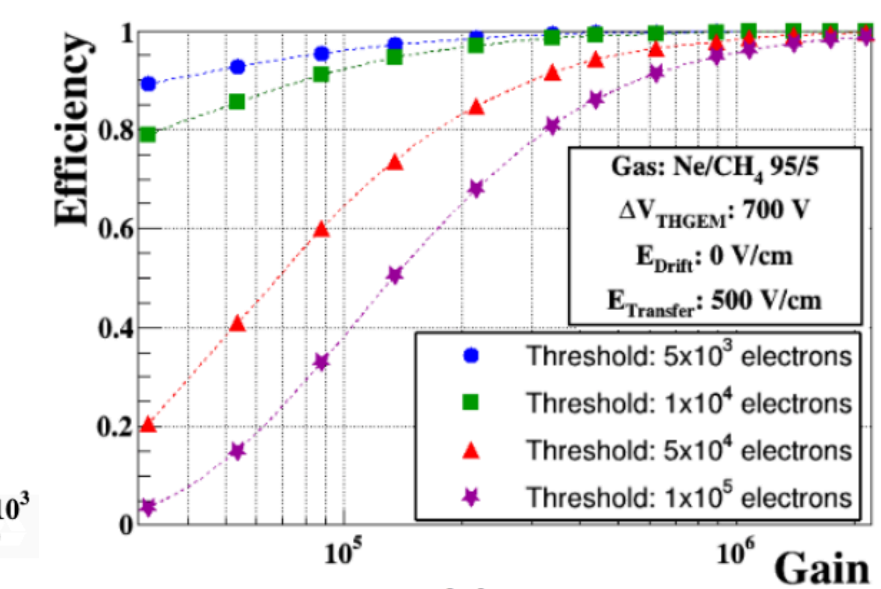


- 5 mm Drift Gap; 2 mm Transfer gap
- 0.6 mm thick CsI-coated Double-sided THGEM
- 0.4 thick Single-sided THGEM
- 0.4 mm thick Semitron as RP

Spectra @ gain ~1.5×10^5







Cryogenic-RPWELL

Can the RPWELL outperform LEMs?

- LEM == THGEM
- RPWELL reached ~100 times higher gain at stable operation conditions relative to THGEM
- If RPWELL is as effective in noble-liquids as it is in room temperature… maybe

Target performance

- 10 better Signal/Noise relative to the LEMs
- Similar or better spatial resolution
- Similar or better energy resolutions

… But we are not there yet…

Challenge I

- Find materials with the right bulk resistivity at LAr temperature (~87 K)

Table 1. List of materials failing to quench discharges at cryogenic temperatures

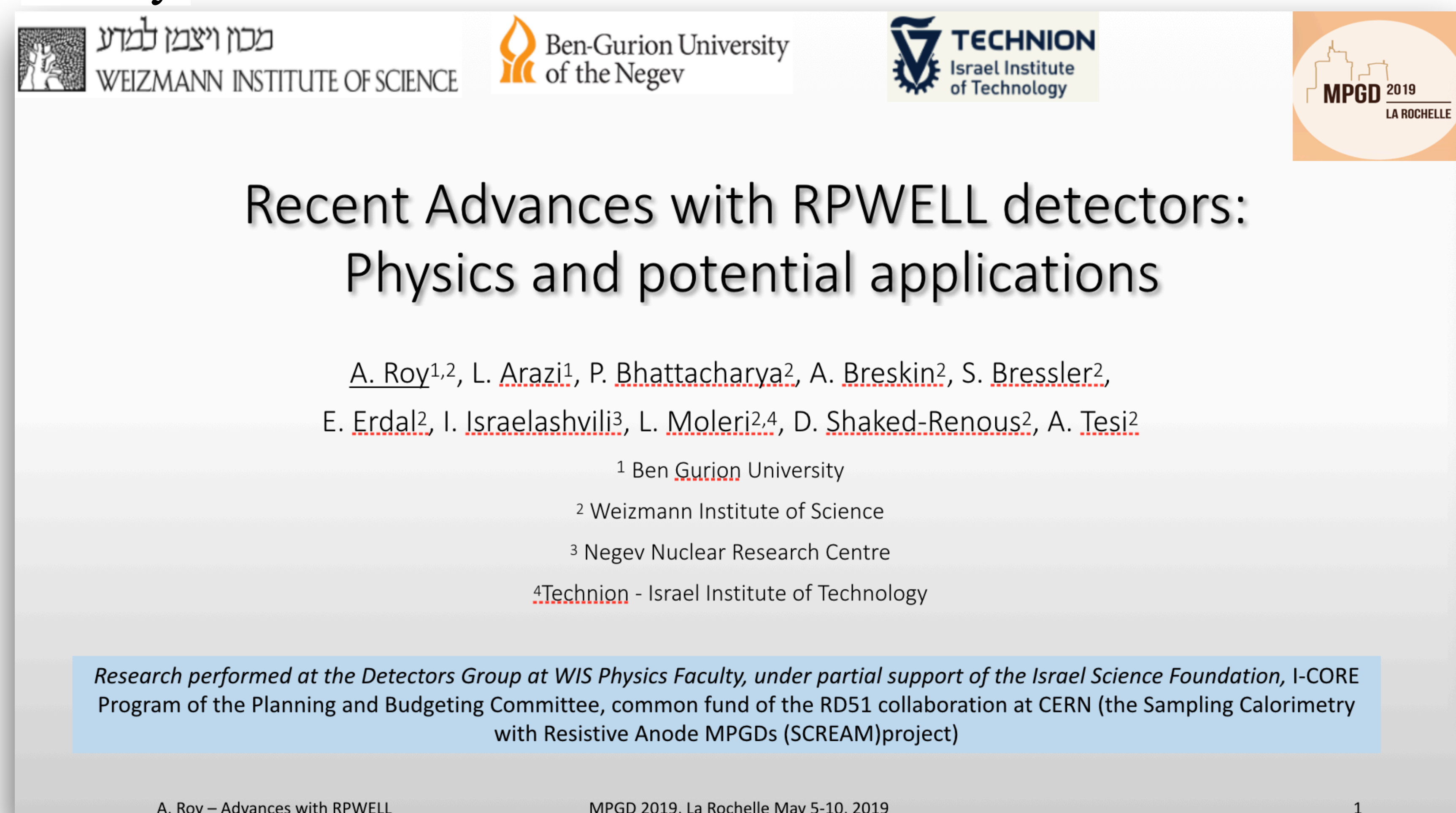
Material	Source	Resistivity @ RT	Resistivity as function of T	Discharge Quenching at Cryo T
Tivar EC & Tivar ESD (UHMW-PE)	J. Vavra SLAC, USA	$\rho \sim 10^6$ - 10^7 Ω·cm	Constant	Fails; low ρ value
PTFE + 1.5% Carbon	3M, USA	$\rho \sim 10^7$ - 10^8 Ω·cm	Constant	Fails; low ρ value
Araldite + Graphite (Graphite - 15-30 %)	Fabricated @WIS	$\rho \sim 10^8$ - 10^{14} Ω·cm	Constant	Fails; non-uniform resistivity
Si-based Ceramics	L. Naumann, HZDR, Germany	$\rho \sim 10^8$ Ω·cm	Increases exponentially with decreasing T	Fails; ρ too high @ LXe T

Cryogenic-RPWELL

- ”First results of Resistive-Plate Well (RPWELL) detector operation at 163 K”, JINST 14 (2019) no.10, P10014

A. Roy, M. Morales, I. Israelashvili, A. Breskin, S. Bressler, D. Gonzalez-Diaz, C. Pecharromán, S. Shchemelinin, D. Vartsky, L. Arazi

A. Roy



Cryogenic-RPWELL

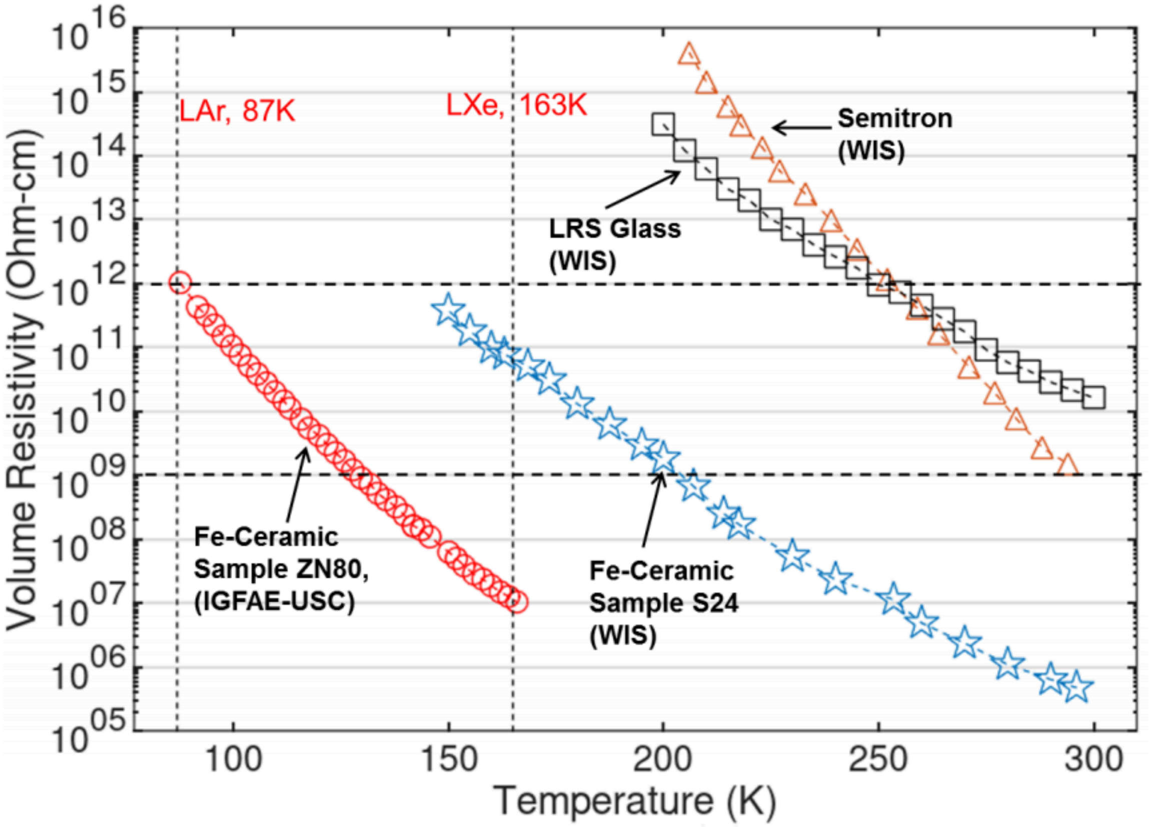
Resistive material

- Target resistivity: $\rho \sim 10^9 - 10^{12}$ Ω-cm @ LXe & LAr T's
- Semitron & LRS Glass (suitable @ RT) $\rho > 10^{14}$ Ω -cm around 200K.

Fe-Ceramics

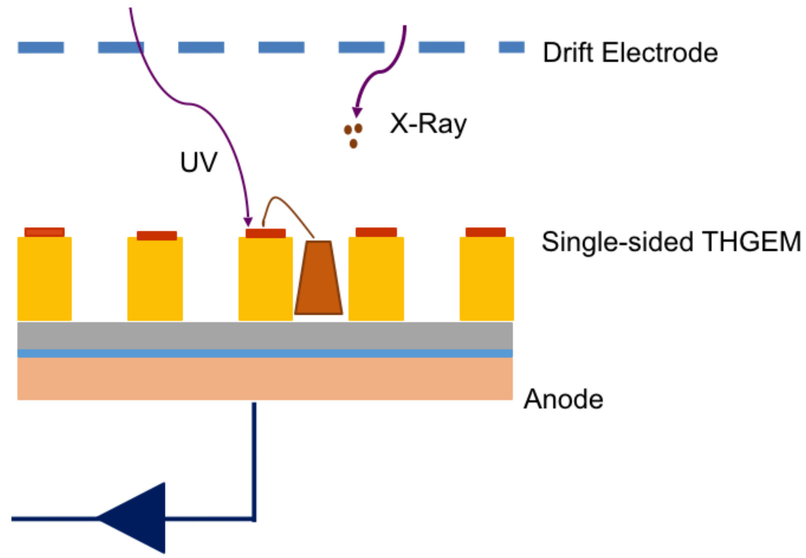
- Robust ceramic composites with tunable electrical properties

  C Pecharromán, M Morales et al; 2013 JINST 8 P01022
- Provided several samples for us
  - Sample S24 : $\rho \sim 10^{11}$ Ω-cm @ LXe Temp (measured in controlled conditions).
  - Preliminary ρ measurements down to LAr T. Promising results with ZN80
- Dedicated experiments ongoing @ IGFAE-USC, Spain and WIS to understand the behavior.



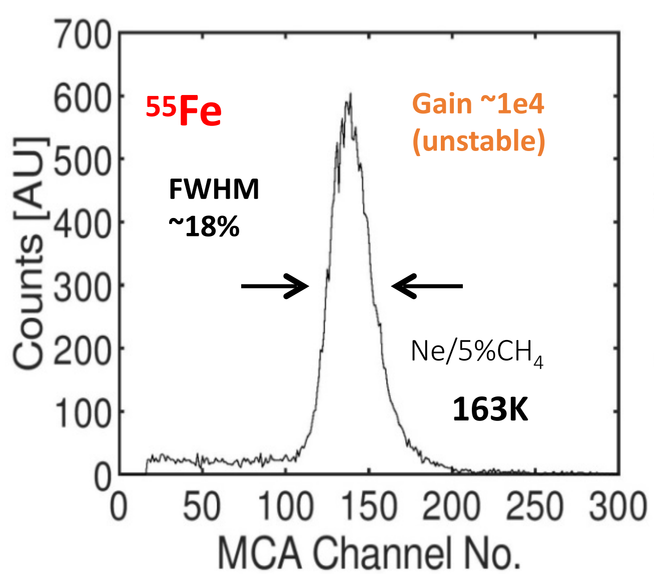
Fe-Ceramic-RPWELL

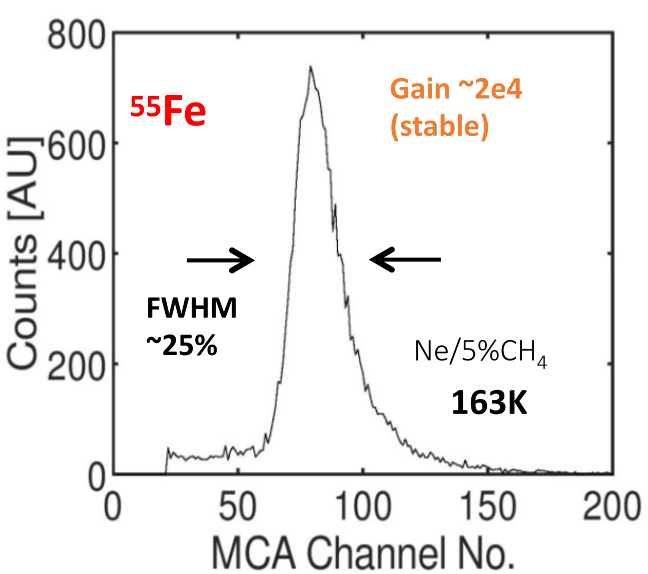
- First proof of discharge-free RPWELL detector operation at 163K
- **Tested in Ne/5%CH_4 at RT & low T in LN_2 + ethanol bath down to 160 K (ρ~ 10^{11} Ω-cm)**
  - **Not in dual-phase Xe**
- Detector investigated with X-rays & single UV-photons (RPWELL without/with CsI photocathode)

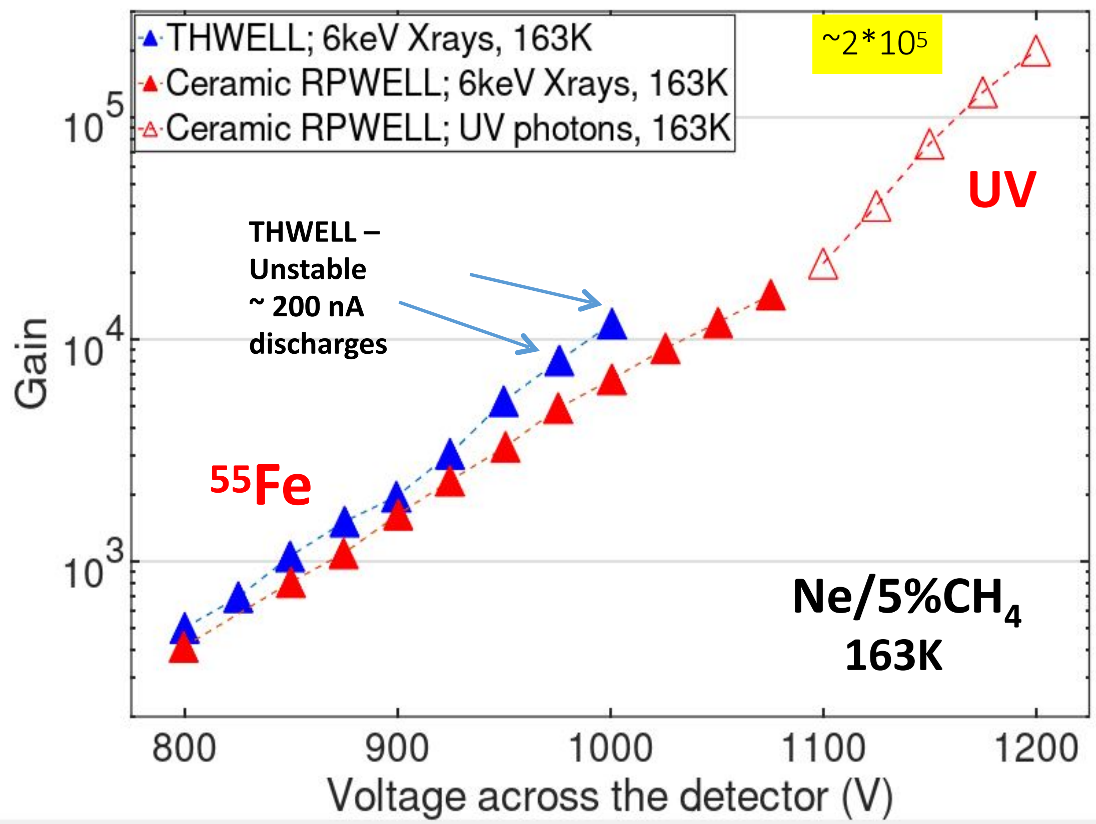


- Performance compared to regular THWELL with no resistive plate
- THGEM/LEM geometry not optimized
  - 0.6 mm thick electrodes

Pulse Height Spectra with X-rays





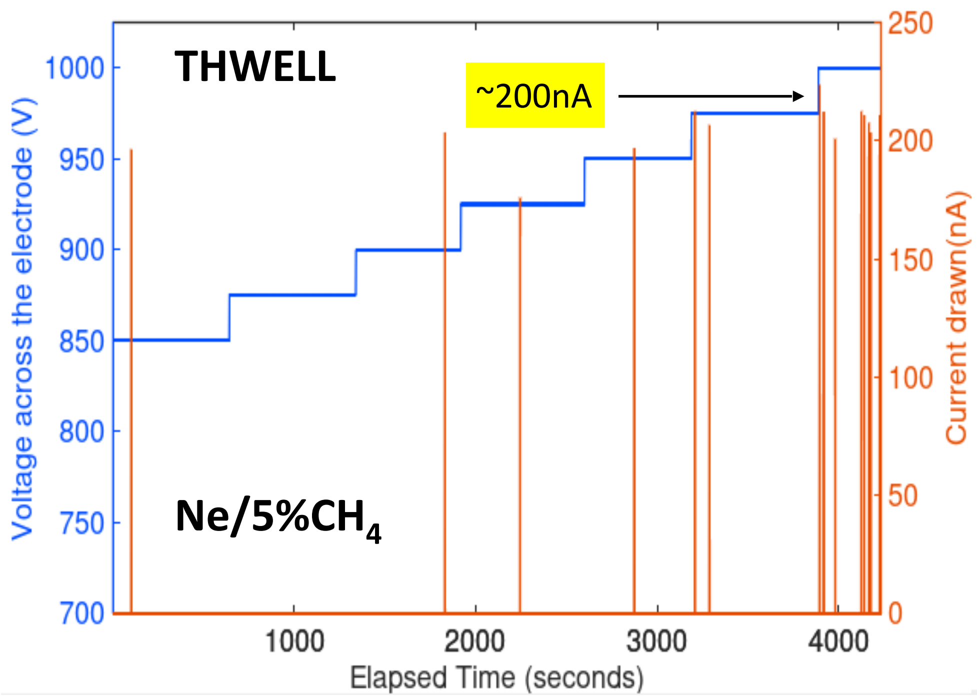


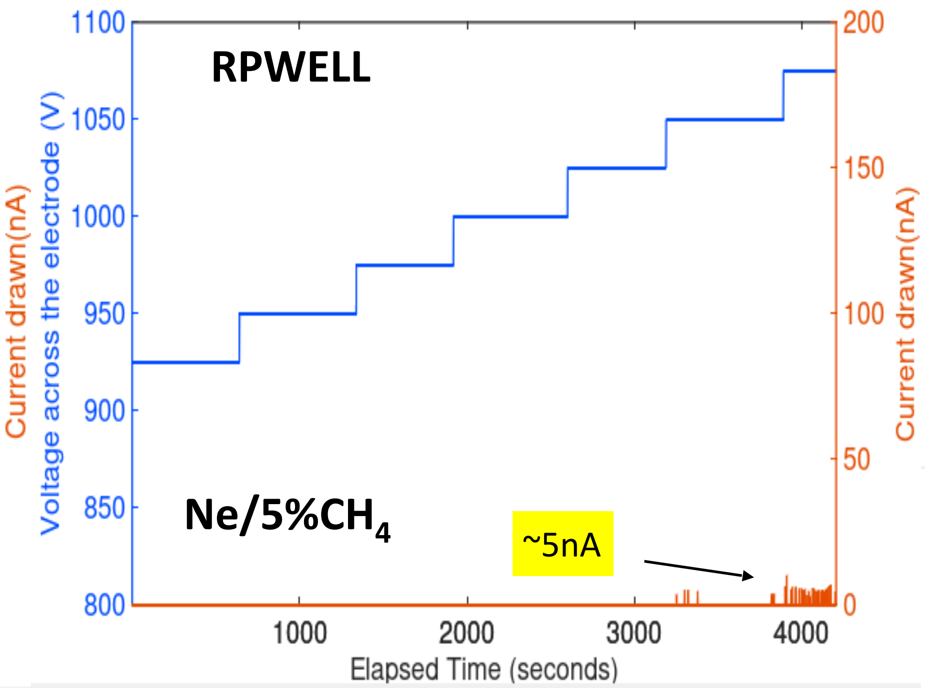
Discharge-free RPWELL operation up to ~10^4 **gain with X-rays**, and **~10^5 with single UV-photons** (without CsI) **@ 163K**

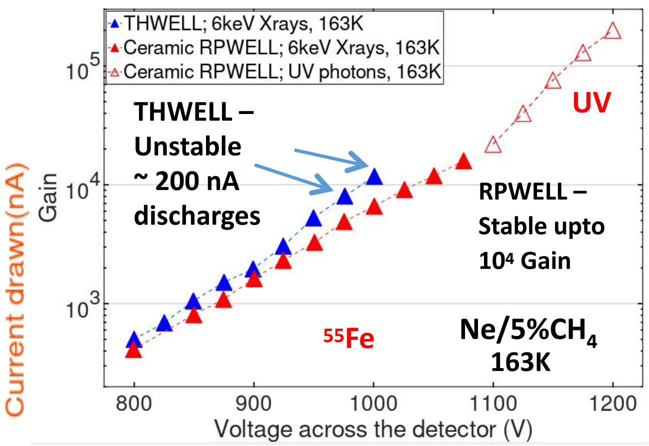
Fe-Ceramic-RPWELL

Discharge behavior

- Cryo-RPWELL: discharge free operation up to a gain of 10^4
  ~5 nA discharges @ gain > 10^4
- THWELL: ~200 nA discharges
  Onset of discharges around a gain of 10^3 (850 V)
  Unstable @ gain of 10^4 with regular discharges



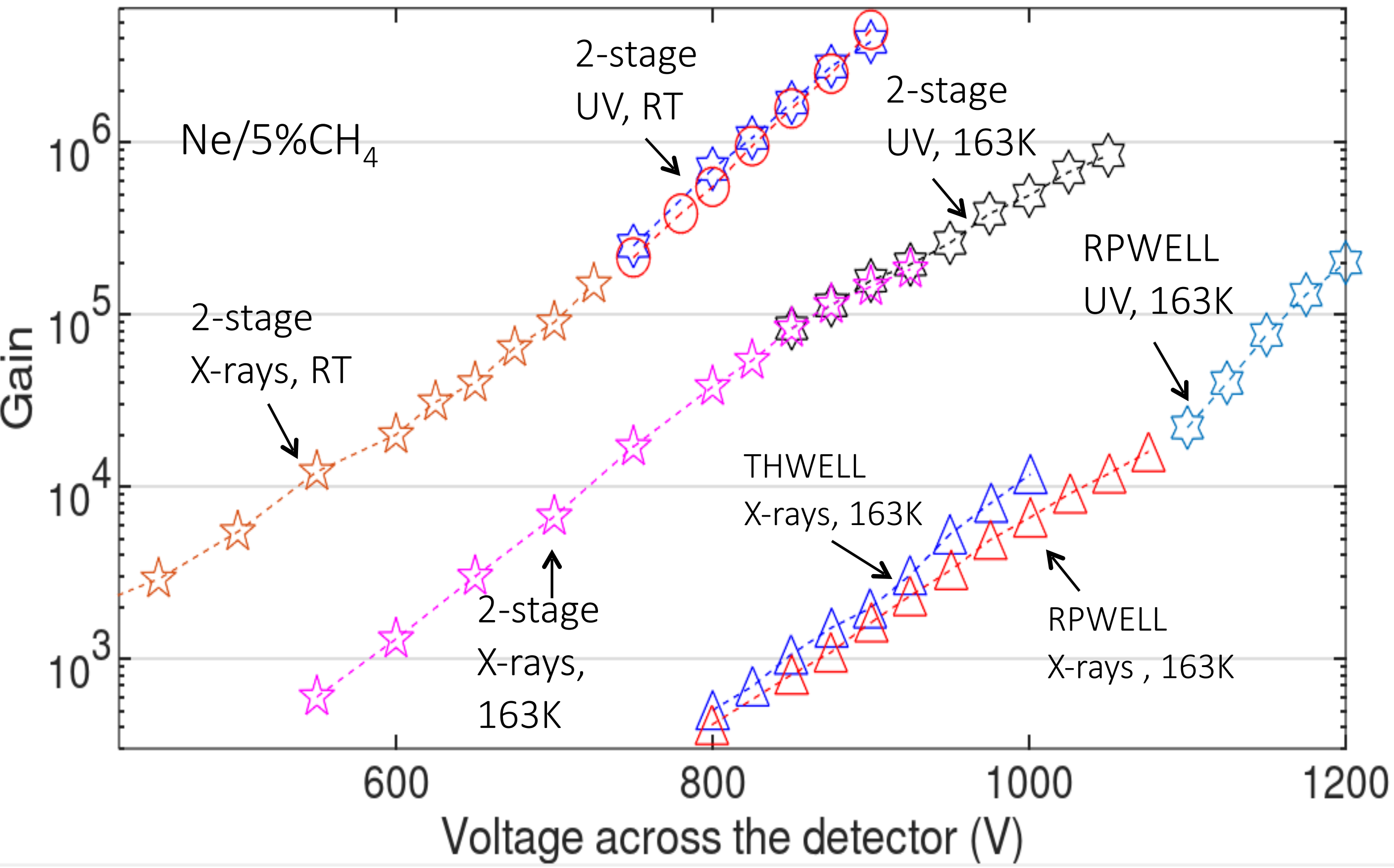


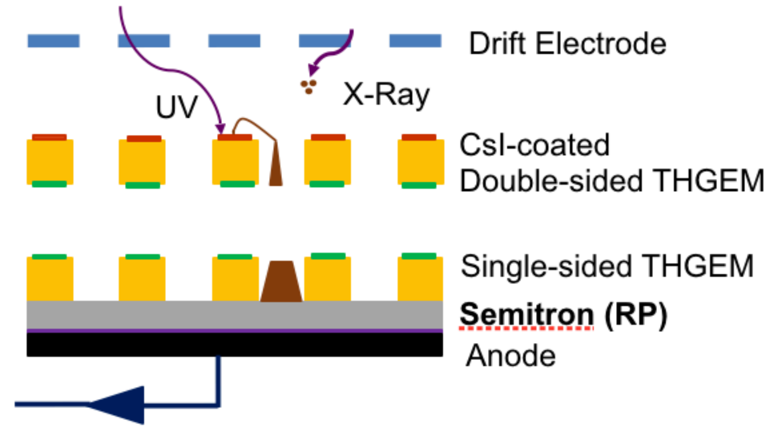


Double stage Cryo-RPWELL

Discharge behavior

- Ne/5%CH_4
- Gain >10^5 with X-rays @ RT and 163K
- Gain >10^6 with single UV photons @ RT and
- Gain ~10^6 @ 163K





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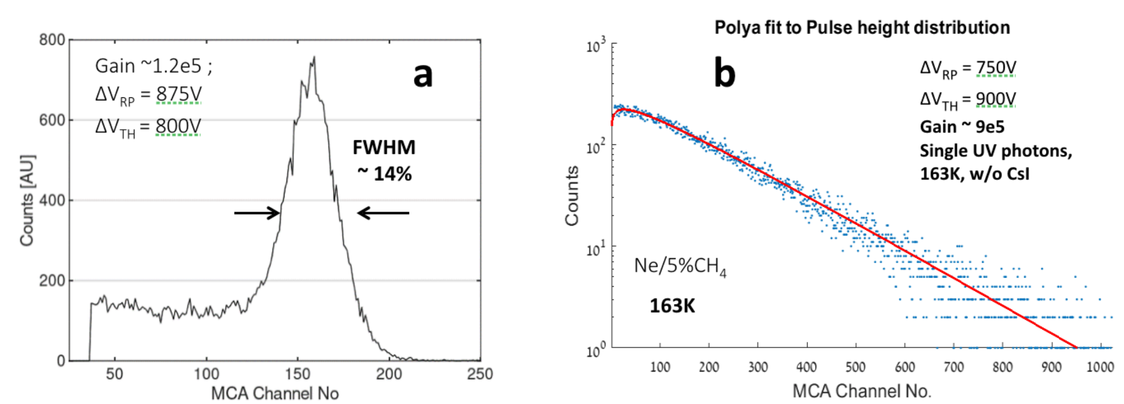


Charge spectra @ 163 K

- ^{55}Fe X-ray: peak with 14% FWHM
- Single photon/electron: Clear Polya

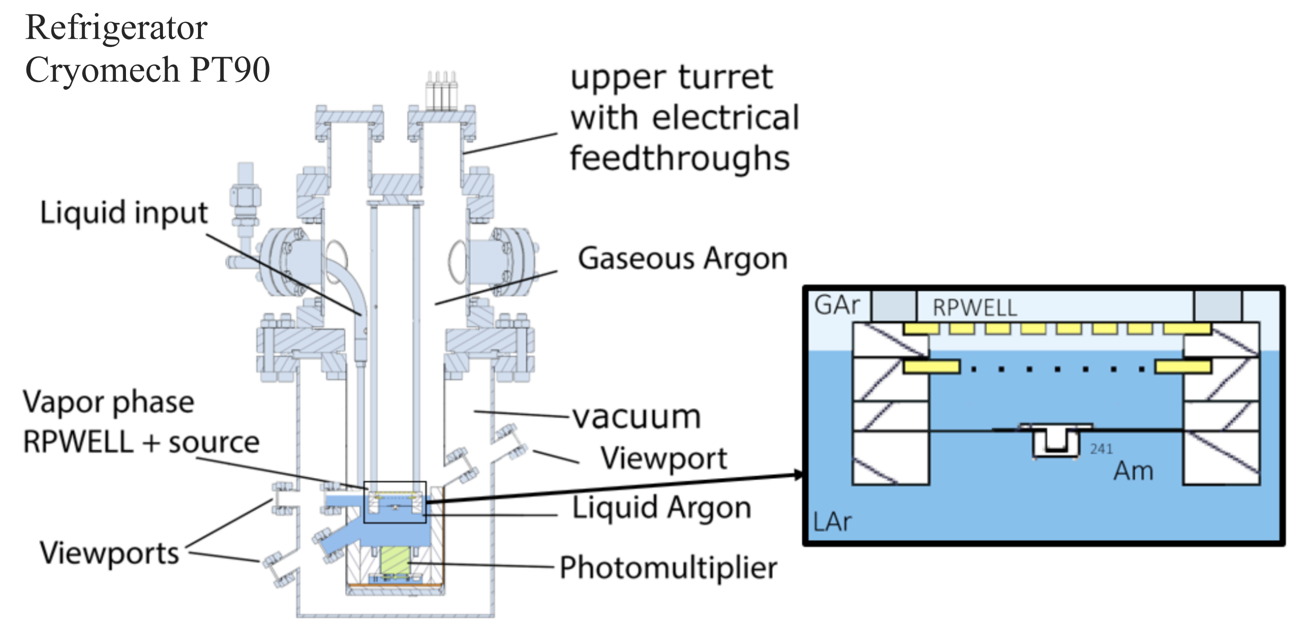
Cryo-RPWELL in Dual phase LAr

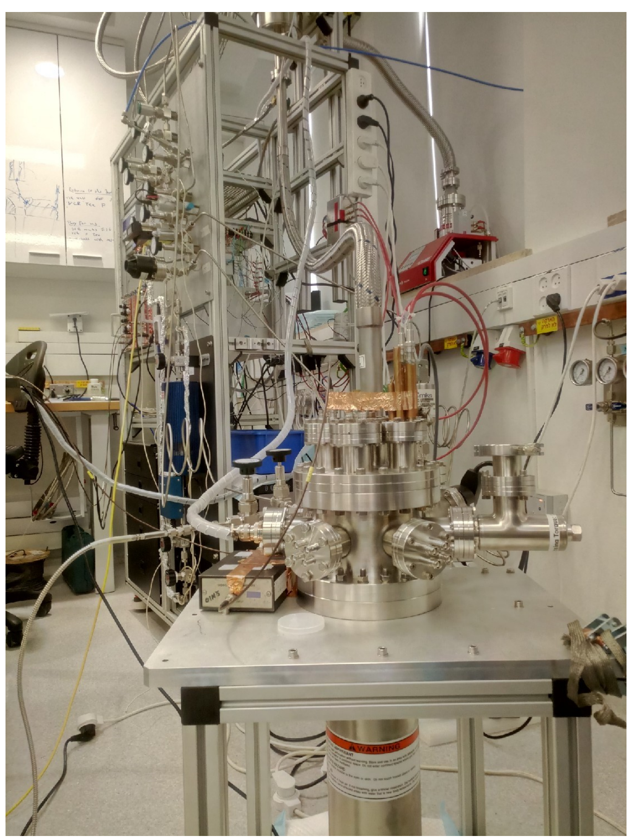
WISArD

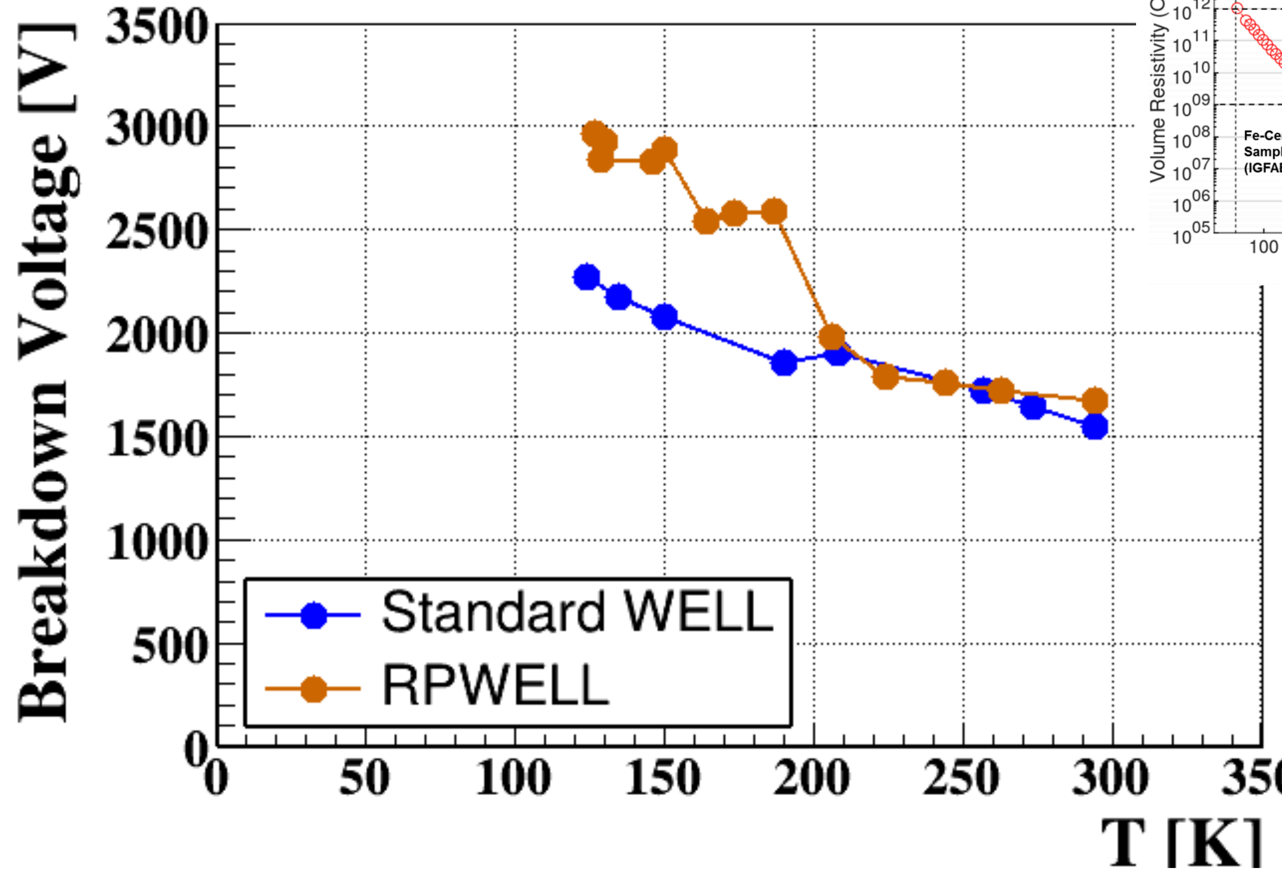
- 200-300K – No difference in breakdown voltages ⇒ Fe-Ceramic

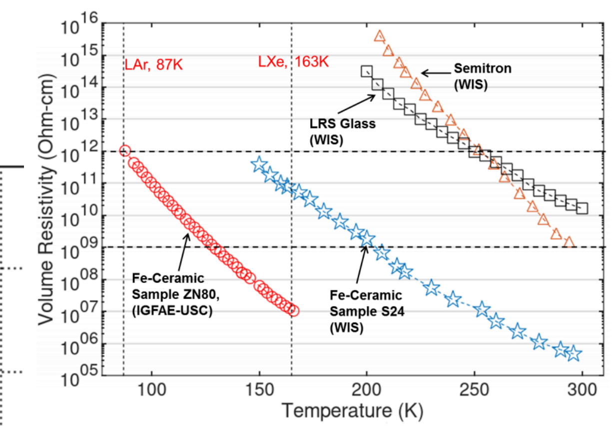
  ρ inadequate to quench discharges
- T< 200K ⇒ ρ ~ 10^9 Ω-cm ⇒

  Effect of RP clearly seen. Higher RPWELL Breakdown Voltages.









Cryo-RPWELL - Quick summary

- The immediate challenge - Material with the right bulk resistivity at CT
- Fe-Ceramics - promising candidate
  - Tunable resistivity values with post treatment curing
- Successful demonstration at LXe temperature
  - Operated with cooled Ne/5%CH4 gas mixture
  - Discharge free operation at high gains
    - > an order of magnitude relative to regular THWELL
    - Both ^{55}Fe x-ray and single UV photons (THWELL coated with CsI photocathode)
  - ***So far only with small area detectors***

Cryo-RPWELL - Next steps

- Demonstration in LAr - active RD51 common grant
  - Get viable sample for LAr
  - Proof of concept in dual phase LAr
  - Optimized geometry for LAr

- And more
  - Other resistive materials
  - Larger areas
  - …..

Request for Project Funding from the RD51 Common Fund

- Date: *28.06.19*-

Title of project: ***Resistive materials and resistive-MPGD concepts & technologies***

Contact person: *Shikma Bressler,*
+972-542887273,
shikma.bressler@cern.ch

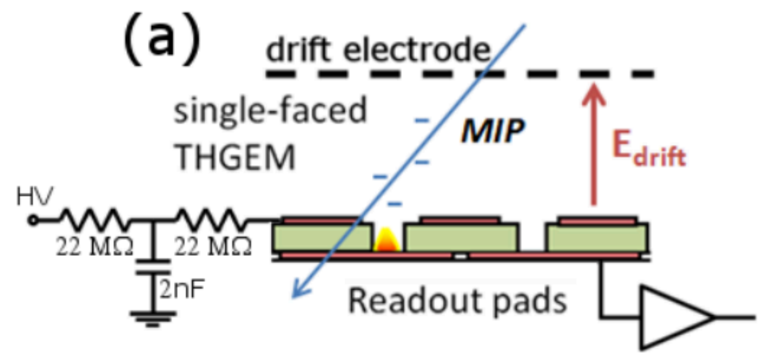
RD51 Institutes:
1. *Weizmann Institute of Science, shikma.bressler@cern.ch*
2. *IGFAE-USC, Diego.Gonzalez.Diaz@cern.ch*
3. *University of Aveiro, cdazevedo@ua.pt*

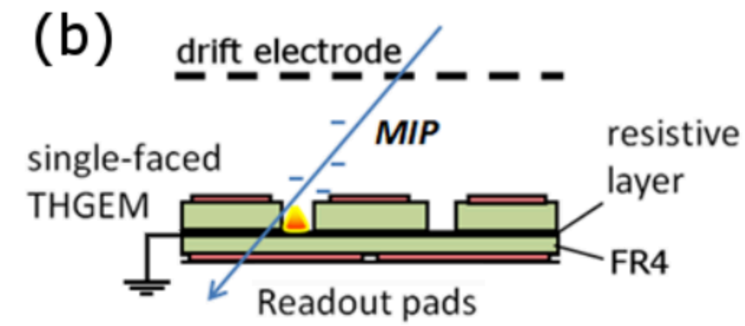
Other institutes: **1.** ICMM-CSIC, *cpg@icmm.csic.es*

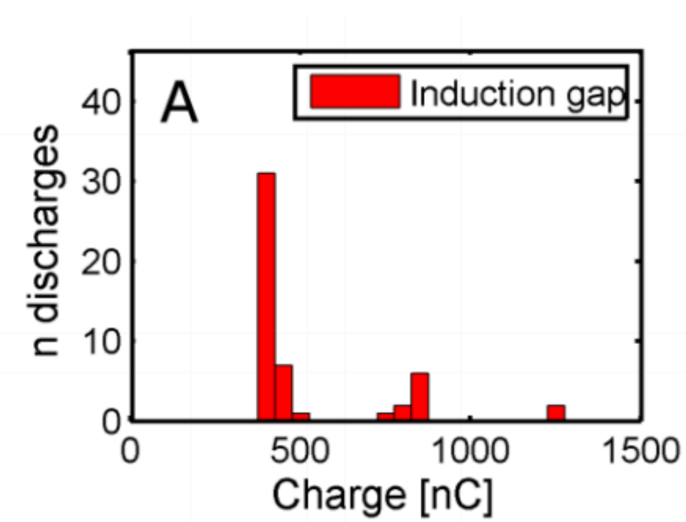
Resistive WELL (RWELL)

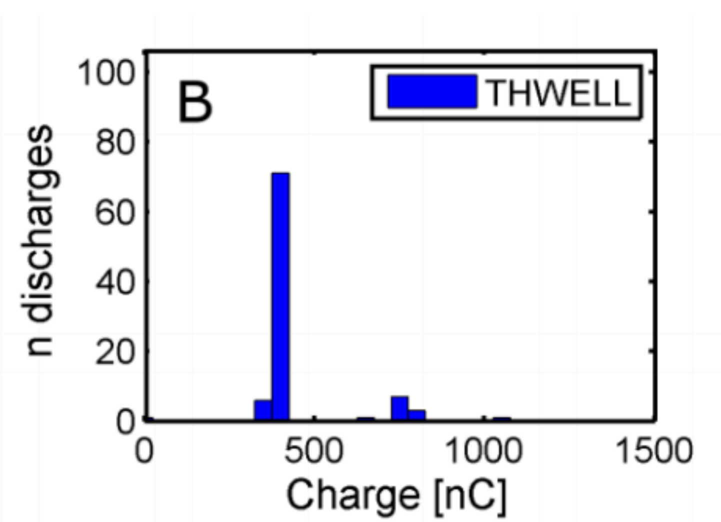
- Directly coupling an single sided THGEM electrode to a ***resistive anode***
  - Scheme similar to the one used, for instance, in the ATLAS TGC
- Found more stable than regular WELL
- Has intrinsic discharge quenching mechanism
- Never studied in the context of cryogenic systems
  - But we wanted to do it many times… so maybe we should…
- Might be easier to implement with DLC-made resistive layer

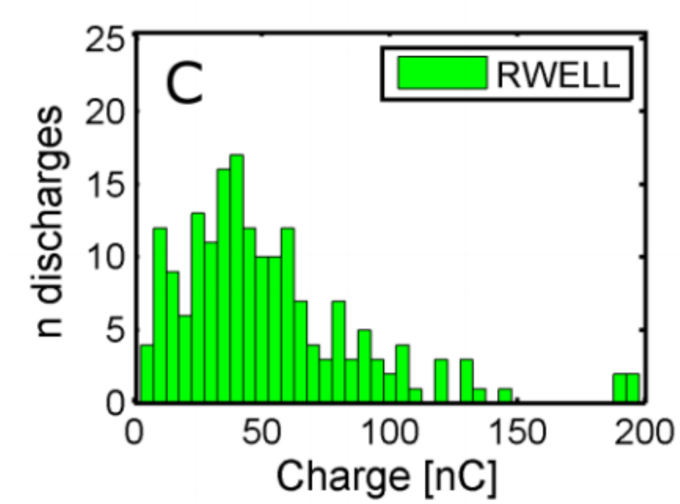
THGEM | Regular WELL | Resistive WELL











Epoxy RPWELL

- FR4 as base material poses known challenges/limitations
  - Thickness uniformity
  - Possibly sharp fragments inside the holes
  - Glass is a source for (low rate) radioactivity
- Constant search for alternative materials

- Epoxy-silver might be an interesting alternative

Epoxy-based RPWELL detectors

Dan Shaked Renous[a], Lior Arazi[b], Amos Breskin[a] and Shikma Bressler[a]

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b. *Ben-Gurion University of the Negev, Beer-Sheva, Israel*

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ABSTRACT: The promising capabilities of the Resistive-Plate WELL (RPWELL) detector motivated the search for new materials and production techniques to avoid the known disadvantages of currently used FR4 substrate. We introduce new type of THGEM electrodes made of epoxy-based SU-8 in a WELL and step-WELL geometries. A systematic comparison of these two electrodes to the conventional FR4-made RPWELL is presented.

KEYWORDS: Materials for gaseous detectors; Charge transport and multiplication in gas; Micropattern gaseous detectors (MSGC, GEM, THGEM, RETHGEM, MHSP, MICROPIC, MICROMEGAS, InGrid, etc)

Epoxy RPWELL

- Produced by a Japanese company called Optnics
  - Communication through an Israeli supplier
  - Good communication
  - Fast response
- The technology is patented
- Typical spreadsheet

Measurement result sheet for Weizmann page.1 2015.11.13 OPT *Optnics Precision*

◆Hole diameter

Hole size	Plate D			Plate E			Plate F		
ϕ0.65 (Electrode) (mm)	0.642	0.641	0.641	0.646	0.646	0.646	0.648	0.648	0.649
ϕ0.5 (1st Epoxy) (mm)	0.493	0.493	0.494	0.498	0.499	0.498	0.504	0.503	0.503
ϕ0.7 (2nd Epoxy) (mm)	0.701	0.701	0.700	0.700	0.700	0.700	0.701	0.702	0.701

◆range of thickness

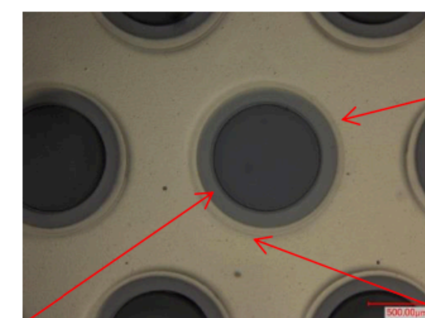
Plate #	min (mm)	Max (mm)
D	0.407	0.429
E	0.383	0.422
F	0.400	0.436

Go to next page to see detail.

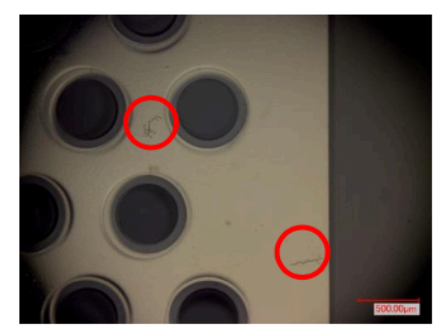
◆center offset between layer

Plate #	ϕ0.65 and ϕ0.5 (mm)	ϕ0.65 and ϕ0.7 (mm)
D	0.005	0.008
E	0.013	0.010
F	0.004	0.010

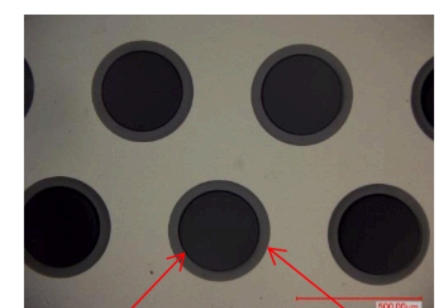
◆appearance



ϕ0.7mm
ϕ0.5mm Bottom(2nd Epoxy) view ϕ0.65mm



Bottom(2nd Epoxy) view
Some part of epoxy has objects.

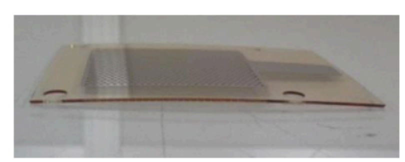


Top(electrode) view
ϕ0.5mm ϕ0.65mm

◆warpage

sample	Warpage (mm)
D	1.517
E	0.643
F	0.709

Samples have gentle curve from one side to opposite side.



Top : Electrode
Bottom : 2nd Epoxy

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Measurement result sheet for Weizmann **page.2**

2015.11.13
OPT
Optnics Precision

◆**Detail of rage of thickness (mm)**

Plate D

○	0.407	0.410	0.411	0.415	0.420
0.406				0.418	0.418
0.407		mesh			
0.410		area			
0.418				0.423	0.429
○	0.426	0.421	0.426	0.423	0.429

Plate E

○	0.394	0.399	0.402	0.393	0.383
0.393				0.390	0.390
0.401		mesh			
0.402		area			
0.407				0.402	0.407
○	0.418	0.402	0.422	0.416	0.418

Plate F

○	0.411	0.427	0.407	0.400	0.404
0.427				0.411	0.400
0.433		mesh			
0.433		area			
0.436				0.409	0.411
○	0.427	0.426	0.422	0.413	0.418

Epoxy RPWELL

- High quality electrodes
  - Already from the first iteration
  - Uniform
  - Precise
  - Concentric
- Easy to make complex geometries
  - Step-hole structure in an attempt to reduce charge up effects

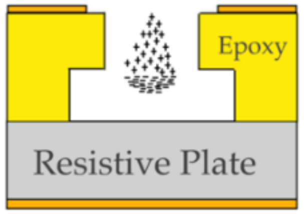

Figure 3. Step-RPWELL configuration

Table 1. Epoxy electrical properties

Dielectric constant:	3-4 (1 GHz, 50%RH)
Dielectric strength:	110-120 V/μm
Resistivity:	10^{16} Ωcm (at 25°C)

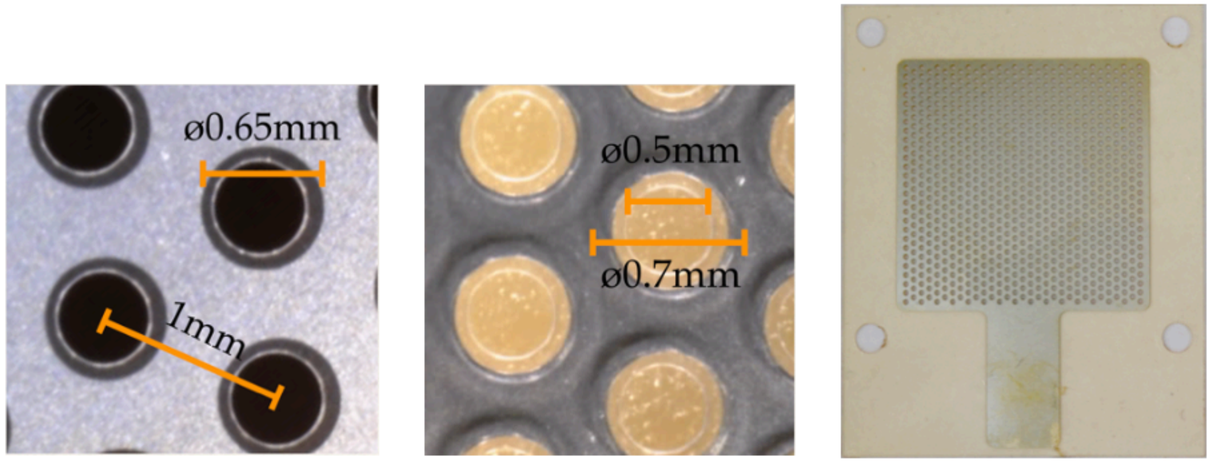

Figure 5. Epoxy 0.4 mm step-WELL electrode (right). Dimensions of the top side (left) and of the bottom side (center).

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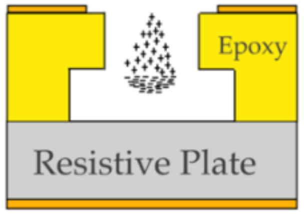

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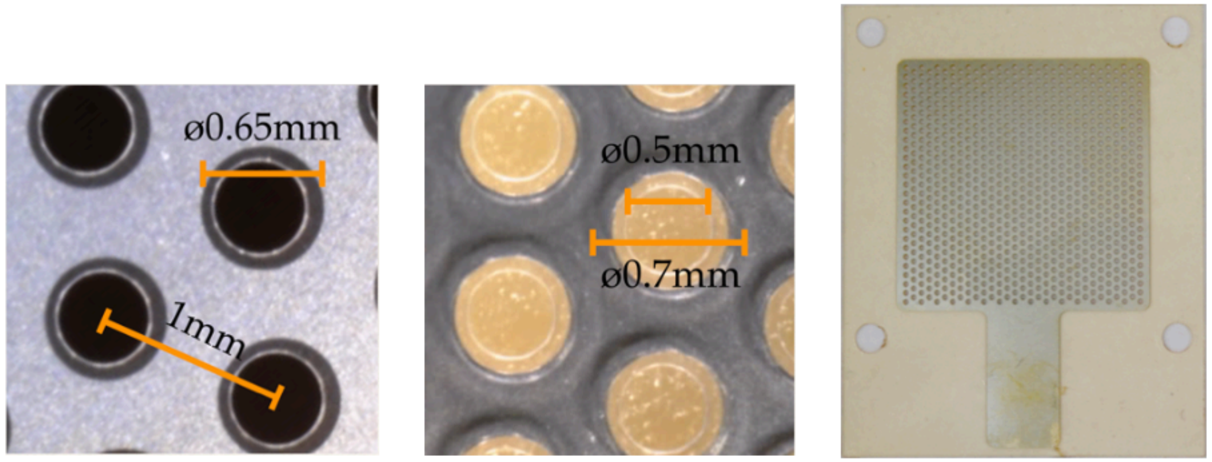

Figure 5. Epoxy 0.4 mm step-WELL electrode (right). Dimensions of the top side (left) and of the bottom side (center).

Epoxy RPWELL - RT

- Performs as FR4-based detectors in terms of
  - Pulse shape
  - Gain
  - Stabilization

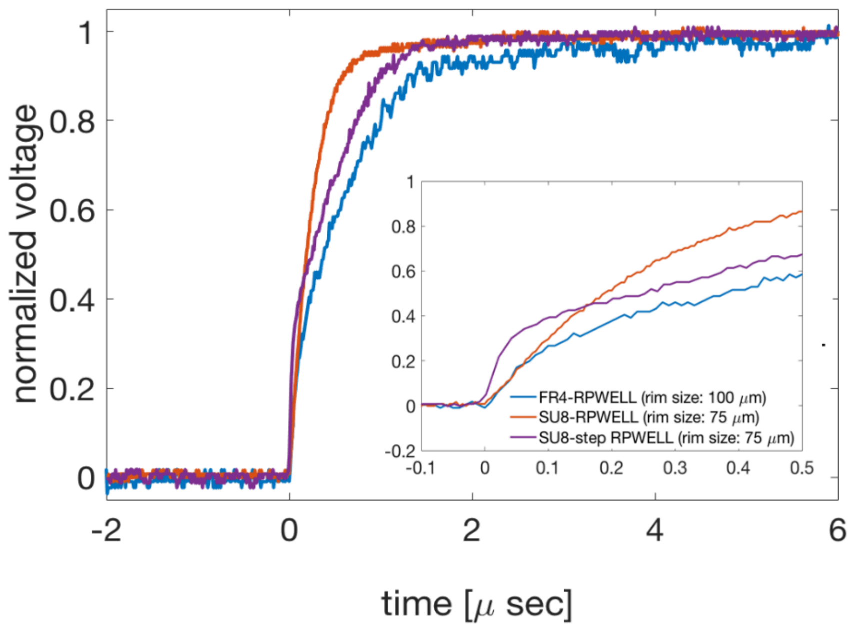

Figure 6. Normalized signal shapes of 8 keV photons obtained by FR4-RPWELL, SU8-RPWELL and SU8-step RPWELL detectors in Ne/5%CH_4.

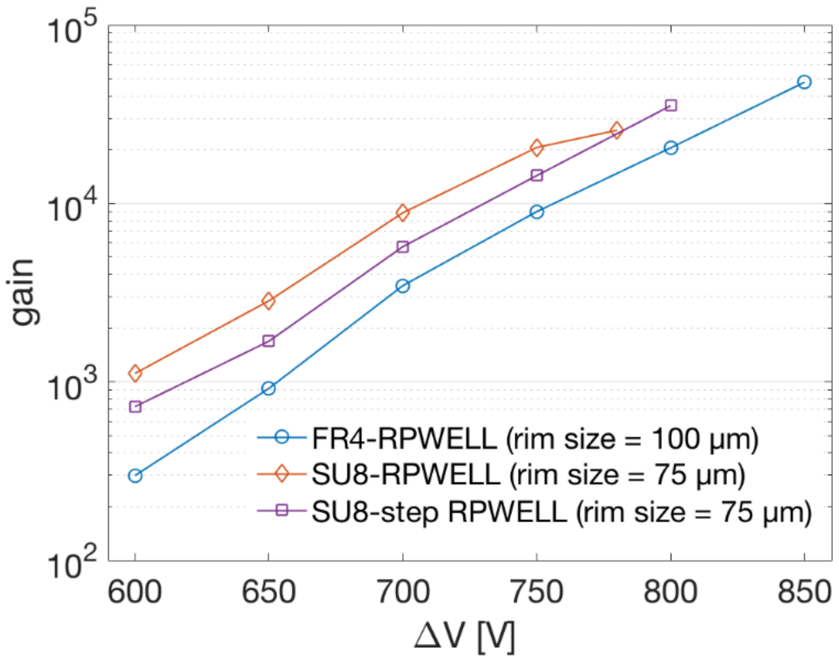

Figure 7. Gain vs. voltage of FR4-RPWELL, SU8-RPWELL and SU8 step-RPWELL detectors. The detectors were operated in Ne/5%CH_4 with 8 keV photons.

Epoxy RPWELL

- Relevant to LAr - electrodes tolerated cooling cycles down to LNi temperature

- Potential scalability
  - Based on email exchange with the company
  - My understanding that it mostly depends on funding…
  - With their already available equipment and methods

1. Default Process

Optnics can provide the following:

- Pattern Max Size [mm]: 28 x 75
- Part Max Size [mm]: 50 x 100

2. New Process

- We are producing similar parts - Induction Encoders application
- The Induction Encoders consist the following layers:
  - Bottom Layer: Aluminum support plate
  - 1st Layer: Epoxy pattern
  - 2nd Layer: Ni/Cu electrode/antenna
- We assume that such structure, can help with production of larger pattern size, and more stable geometry

Summary

- RPWELL poses an internal discharge quenching mechanism
- Successfully demonstrated with Fe-ceramic
  - Stable operation up to gain of 10^5
  - Unoptimized detector geometry (0.6 mm thick electrode)
  - In NeCH4 gas mixture
  - Cooled down to 167 K (LXe)

- Resistive WELL (RWELL) is also worth studying
  - Maybe with DLC resistive layer
  - Charge evacuated to the sides rather than through the bulk resistive material

- Epoxy has some advantages relative to FR4
- Epoxy-based THGEM behaves like an FR4-based one
- Tolerates cooling cycles
- Potentially interesting R&D direction